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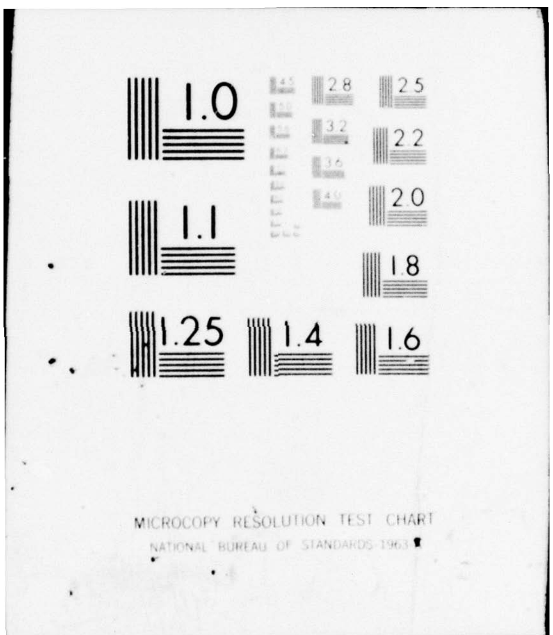
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ANOTHER METHOD FOR ESTIMATING CLEAR COLUMN RADIANCES

By

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October 1976

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An algorithm for estimating clear column radiances from an array of satellite observations is presented. The procedure is iterative and uses the principles of editing about a least squares planar estimate. Examples of data processed by using this technique are given.

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CONTENTS

INTRODUCTION

During the last decade, considerable research has addressed the problem of satellite remote sensing of atmospheric temperature profiles. The satellite observed radiance can be expressed through the radiative transfer equation as a function of the temperature profile, the atmospheric transmittance, and the amount, height, and optical properties of clouds in the field of view of the instrument. Measurements are usually taken at a number of temperature sounding frequencies where the atmospheric transmittance is assumed to be known.

Since the atmosphere is rarely cloud free, it is necessary to eliminate or account for the effect of clouds on the observed radiances in order to obtain the atmospheric temperature profile. When clouds exist in the field of view

$$I(\nu) = NI_{cld}(\nu) + (1 - N)\, I_{clr}(\nu)$$

where $I(\nu)$ is the measured radiance, N is the fraction of the field of view covered by clouds, ν is the sounding frequency, $I_{cld}(\nu)$ is the average radiance from the cloud covered portion of the field of view, and $I_{clr}(\nu)$ is the average radiance from the cloud-free portion of the field of view.

In general, in the "solution of the cloud problem," one attempts to determine $I_{clr}(\nu)$ from the observations. Two exceptions to this approach are given by Rogers [1] and Chahine [2]. Two basic approaches have been suggested for dealing with clouds. One utilizes measurements of a single field of view; the other employs multiple fields of view. Derivations and discussions of several of these techniques can be found in the papers cited in the bibliography.

This report discusses a new multiple field-of-view method which is based upon less restrictive assumptions than Smith's [3] model which has been used operationally by the National Environmental Satellite Service (NESS), McMillian et al. [4].

SMITH'S TWO-FIELD-OF-VIEW MODEL

The following discussion is extracted from the paper by Smith [3]:

Writing Eq. (1) for two different resolution elements subscripted by 1 and 2 gives

$$I_1(\nu) = N_1\, I_{cld1}(\nu) + (1 - N_1)\, I_{clr1}(\nu) \qquad (2)$$

$$I_2(\nu) = N_2\, I_{cld2}(\nu) + (1 - N_2)\, I_{clr2}(\nu) \tag{3}$$

A solution for the average clear column radiance can be obtained if $N_1 \neq N_2$. The fulfillment of this requirement can easily be determined from the measured window radiances, $I(w)$, since for this condition $I_1(w) \neq I_2(w)$.

If the resolution elements are relatively small and adjacent, it is reasonable to assume that $I_{cld1}(\nu) = I_{cld2}(\nu)$ and $I_{clr}(\nu) = I_{clr1}(\nu) = I_{clr2}(\nu)$ where $I_{clr}(\nu)$ is the clear column radiance which is assumed to be constant throughout both resolution elements. Under these assumptions Eqs. (2) and (3) may be solved to obtain

$$I_{clr}(\nu) = \frac{I_1(\nu) - N^* I_2(\nu)}{1 - N^*} \tag{4}$$

where $N^* = N_1/N_2$. N^* may be calculated from the window channel. From Eq. (4)

$$N^* = \frac{I_1(w) - I_{clr}(w)}{I_2(w) - I_{clr}(w)} \tag{5}$$

The value of $I_{clr}(w)$ may be computed from either an in situ measurement or from an estimate of the surface temperature.

The procedure for using this model in operational processing by the NESS is described by McMillian et al. [4].

DISCUSSION

Several problems with the method presented in the previous section can be identified: (a) The surface temperature is not well-known, especially over continental areas where topographic and vegetative differences can exert considerable influence; (b) Measurement error tends to be amplified by the factor $1/(1 - N^*)$; (c) The major assumption that the average radiance arising from the cloud-covered (and also from the cloud-free) area is the same for both resolution elements.

A less restrictive assumption on the behavior of the clear column radiance will now be considered. For notational purposes, let $R(\nu,x,y)$ denote the clear column radiance for the resolution element centered at position x, y. Over the geographical area of interest, it will be assumed that $R(\nu,x,y)$ varies linearly in x and y, i.e.,

$$R(\nu,x,y) = A(\nu) + B(\nu)\, x + C(\nu)\, y \tag{6}$$

Observe that Smith's assumptions are the degenerate case $B(\nu) = C(\nu) = 0$. Given a set of $R(\nu,x,y)$ the coefficients in Eq. (6) can be determined by standard least squares curve fit techniques. Unfortunately, the set $R(\nu,x,y)$ is not given; instead a set of measurements, say $\hat{R}(\nu,x,y)$, is given from which $R(\nu,x,y)$ is to be determined.

Sample sets of measured radiance data for the window channel of the NOAA-4 VTPR are shown in Tables 1 and 2. A rectangular array of seven consecutive scan lines and seven consecutive scan spots was chosen for this analysis.

The technique consists of two steps. The first step is to determine if a given observation is contaminated by clouds; the second step is to synthesize "clear column" radiance for those observations which are cloud contaminated.

An editing procedure is used to determine those points which are cloud contaminated. The following steps are used:

1. Points which are obviously cloud contaminated are determined and flagged.

2. Equation (6) is fit to the unflagged points.

3. An rms of deviations about the plane is computed. Only unflagged points are considered.

4. Any point with a deviation below the plane of more than 2 times the rms is flagged.

5. Steps 2 through 4 are repeated until no new points are flagged.

Those points which were not flagged are now considered to be clear. Equation (6) is now fit to these remaining points. The value predicted by the plane is used to synthesize "clear column" radiances for those points which were flagged.

Various procedures are available for step 1. A procedure which works well in practice is based on the observation by Chahine [5] that

$$\frac{I_{clr}(\nu_1) - \tilde{I}(\nu_1)}{I_{clr}(\nu_2) - \tilde{I}(\nu_2)} = \frac{I_{cld}(\nu_1, P_c) - I_{clr}(\nu_1)}{I_{cld}(\nu_2, P_c) - I_{clr}(\nu_2)} \tag{7}$$

for a single cloud at altitude P_c. (ν_1 and ν_2 are two-cloud sounding frequencies and $\tilde{I}$ is the measured radiance. In practice $\nu_2 = 749\ cm^{-1}$ and $\nu_1 = 725\ cm^{-1}$ have been used for the NOAA-4 data.) For $P_c <$ pressure of the tropopause, the left side of Eq. (7) is a monotone decreasing function of P with equality at $P = P_c$. With this in mind $P_c = 300$ mbs is set arbitrarily and the observation at step 1 is flagged if the right side of Eq. (7) exceeds the left side. This procedure has produced good results in practice.

Two applications of this technique are shown in Tables 1 and 2. In the portion of the tables labeled "original data," the underscored values are those observations which were flagged at step 1. Underscored values in the lower part of the table indicate observations which were flagged at either step 1 or 4, and the values which appear are those which have been synthesized to replace the original observations.

CONCLUSION

An algorithm for estimating clear column radiances has been presented and discussed. The procedure is iterative and uses the principles of editing about a least squares planar estimate.

Examples are shown for data taken over White Sands Missile Range (WSMR), NM, which indicate that the procedure does a reasonably good job of analyzing individual observations.

TABLE 1

NOAA-4 VTPR OBSERVATIONS FOR 20 FEB 75 CENTERED OVER WSMR, NM

a. Original data

	Spot						
Line	13	14	15	16	17	18	19
1	104.50	102.75	99.80	99.20	95.40	95.10	91.30
2	105.95	105.05	103.30	96.00	96.30	96.00	88.70
3	106.55	106.25	99.20	101.55	101.55	94.85	86.35
4	111.80	105.65	103.60	102.75	101.25	92.20	94.25
5	106.80	107.10	104.75	104.20	99.80	102.15	98.90
6	108.85	107.40	104.45	107.10	105.50	104.75	98.50
7	110.35	107.10	105.35	105.35	102.15	98.90	97.75

b. Data after cloud editing

1	104.50	102.75	99.80	99.20	95.40	95.10	91.30
2	105.95	105.05	103.30	100.42	96.30	96.00	94.60
3	106.55	106.25	103.35	101.55	101.55	94.85	95.70
4	111.80	105.65	103.60	102.75	101.25	98.79	94.25
5	106.80	107.10	104.75	104.20	99.80	102.15	98.90
6	108.85	107.40	104.45	107.10	105.50	104.75	98.50
7	110.35	107.10	105.35	105.35	102.15	98.90	97.75

See text for explanation of underlined entries.

TABLE 2

NOAA-4 VTPR OBSERVATIONS OVER WSMR FOR 9 SEP 75

a. Original data

	Spot						
Line	7	8	9	10	11	12	13
1	109.65	121.40	119.65	115.25	100.20	109.05	102.55
2	106.10	115.25	119.65	105.50	109.95	104.65	102.85
3	117.90	119.65	119.05	93.75	99.90	100.50	92.25
4	127.00	125.25	123.45	97.85	88.75	102.85	98.45
5	120.25	124.35	125.25	119.35	92.55	109.05	106.10
6	119.65	124.35	124.95	121.70	98.75	116.40	117.00
7	123.75	121.70	123.75	122.60	103.75	116.40	118.15

b. Data after cloud editing

1	121.62	121.40	119.65	115.25	110.04	109.05	102.55
2	123.25	115.25	119.65	114.46	109.95	104.65	102.85
3	117.90	119.65	119.05	116.09	113.26	110.46	107.64
4	127.00	125.25	123.45	117.72	114.89	112.08	109.27
5	128.12	124.35	125.25	119.35	116.52	109.05	106.10
6	129.74	124.35	124.95	121.70	118.14	116.40	117.00
7	123.75	121.70	123.75	122.60	119.73	116.40	118.15

See text for explanation of underlined entries.

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